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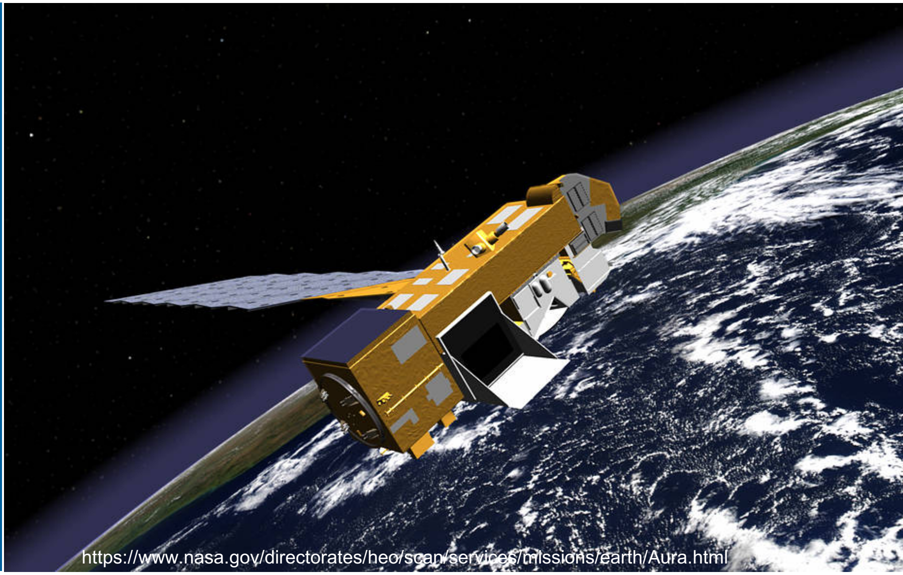
Using OMI NO_2 to infer fossil-fuel emissions of CO_2 from large metropolitan areas in the United States



Goldberg et al., 2019; Science of the Total Environment (click here for paper)

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NASA Aura Science Team Meeting

MOTIVATION

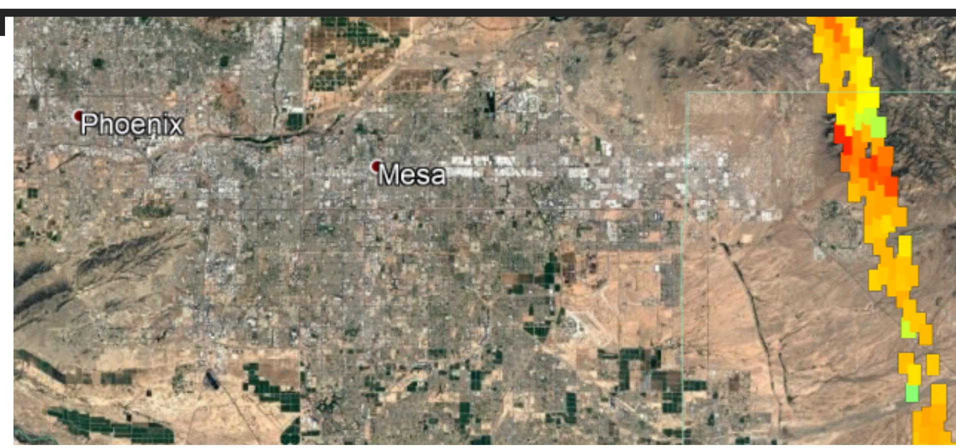
- Strong desire from researchers and policymakers to better refine CO_2 emissions inventories.
- There have been several methods to compute "top-down" CO_2 emissions:

Using OMI NO_2 to infer CO_2 can be very powerful because:

1. There are ~daily overpasses everywhere on the Earth
2. OMI has a consistent long-term record (2005 – present)
3. Isolates the anthropogenic signal in urban areas

- P
  is the *very* narrow swath

OCO-2 swath is ~5 km wide. Any location on Earth may only have 1 or 2 overpasses *per year*!



METHODOLOGY

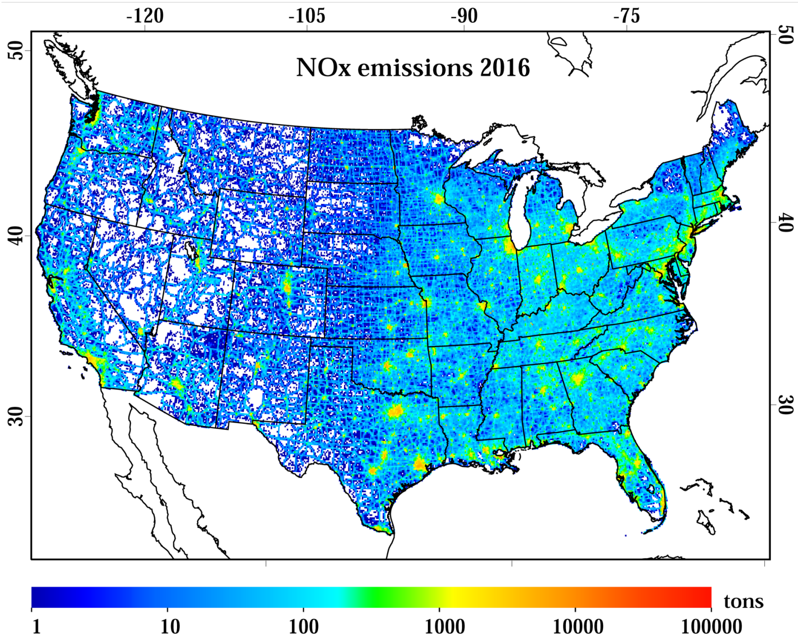
1. Develop a spatially disaggregated bottom-up emissions inventory of CO_2 and NO_X at 1 x 1 km^2 using EPA state-level data
   - Power plant emissions are known, on-road emissions disaggregated based on road density, all other emissions are disaggregated based on population.

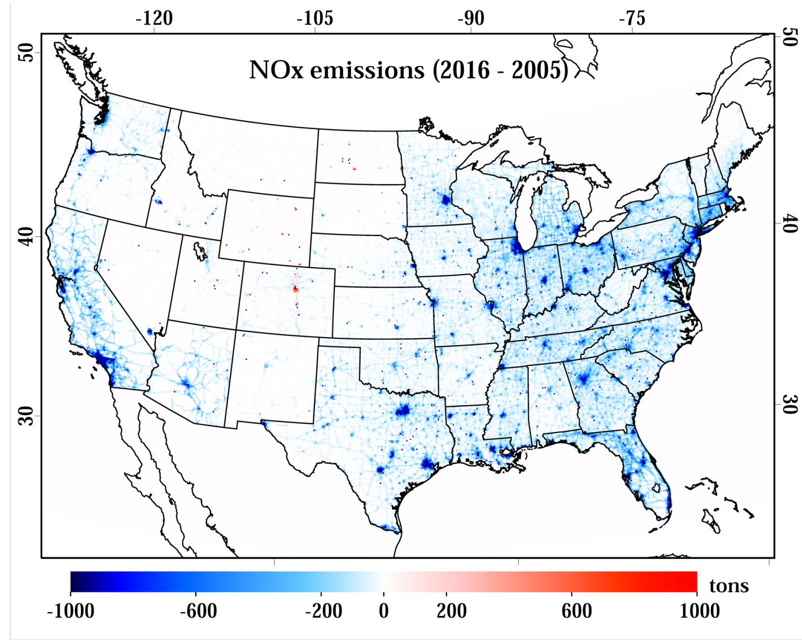
2. Derive top-down NO_X emissions for 8 U.S. megacities using OMI NO_2
   - Use a statistical fit of the oversampled NO_2 plume to derive the NO_2 burden and lifetime.
   - Use NO_2 burden & lifetime to calculate a NO_x emissions rate (Beirle et al., 2011; McLinden et al., 2014; Lu et al., 2015; Liu et al., 2107; Goldberg et al., 2019)

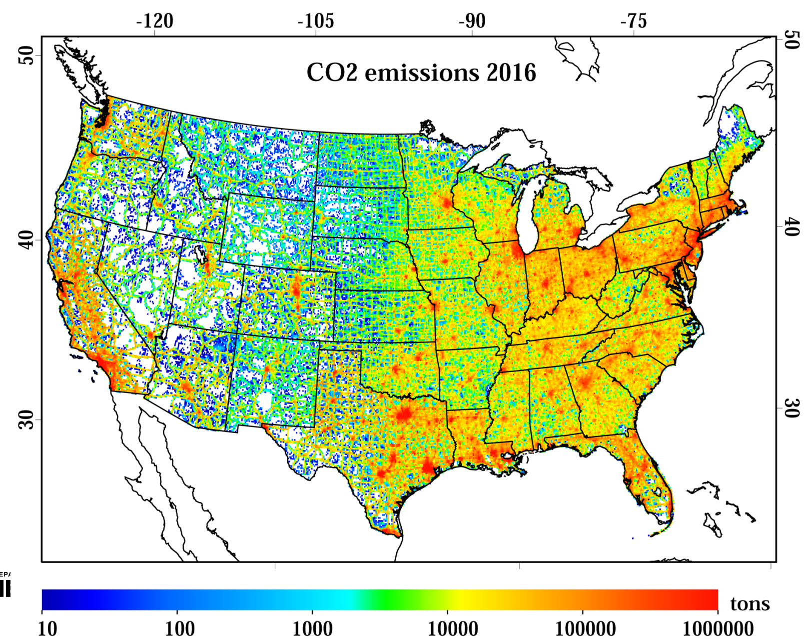
3. Combine top-down NO_X emissions with NO_x-to-CO_2 ratios developed from the bottom-up emissions inventory to calculate top-down "OMI" CO_2

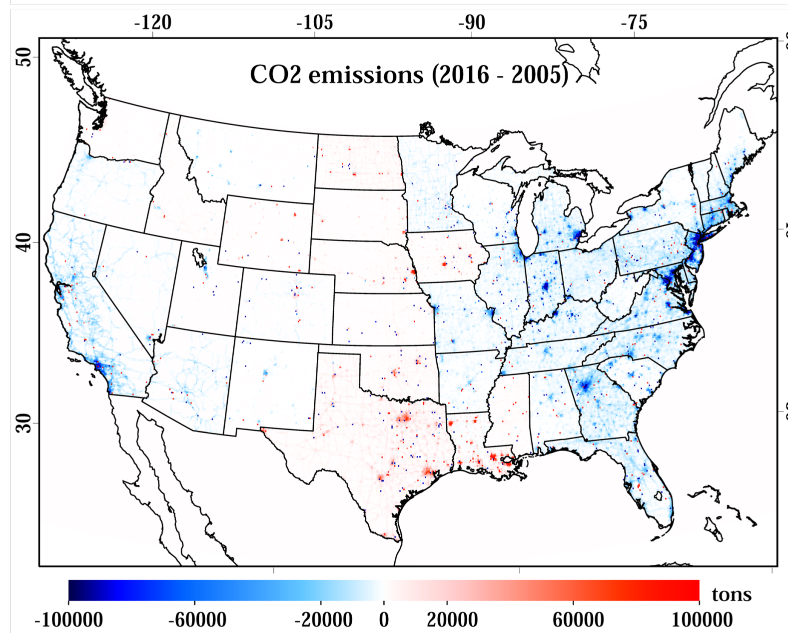
> Main assumption of this work: Emission factors are roughly correct, but that activity data (i.e., when/where fuel is burned) is the unknown.
>
> Main advantage of this work: Isolate fossil-fuel emissions, minimal influence from biosphere!

PART 1: ANNUAL BOTTOM-UP EMISSIONS





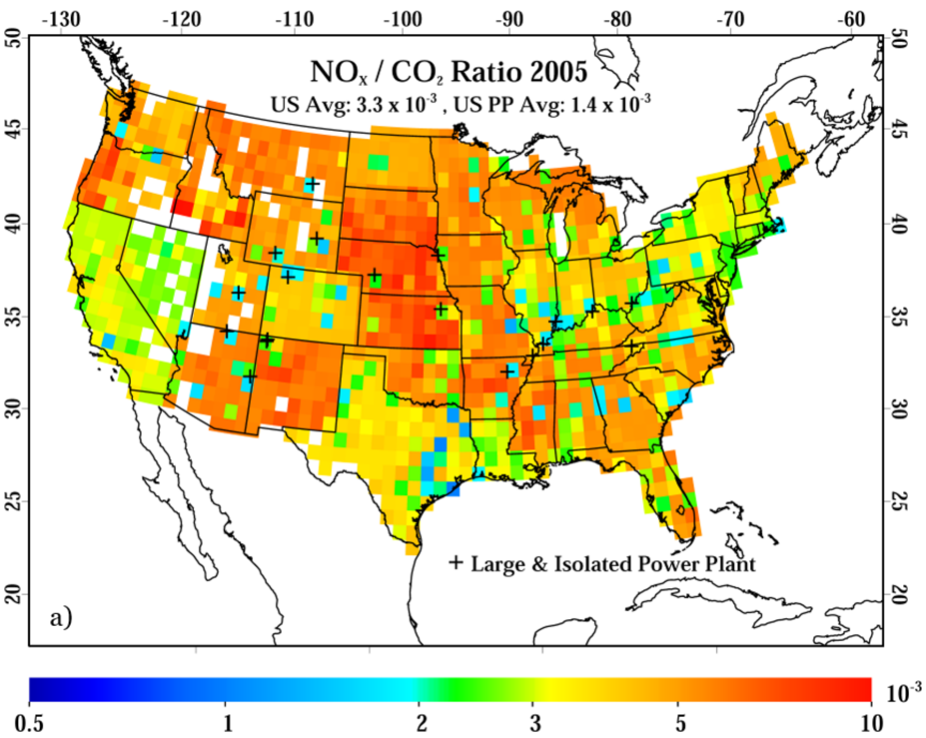




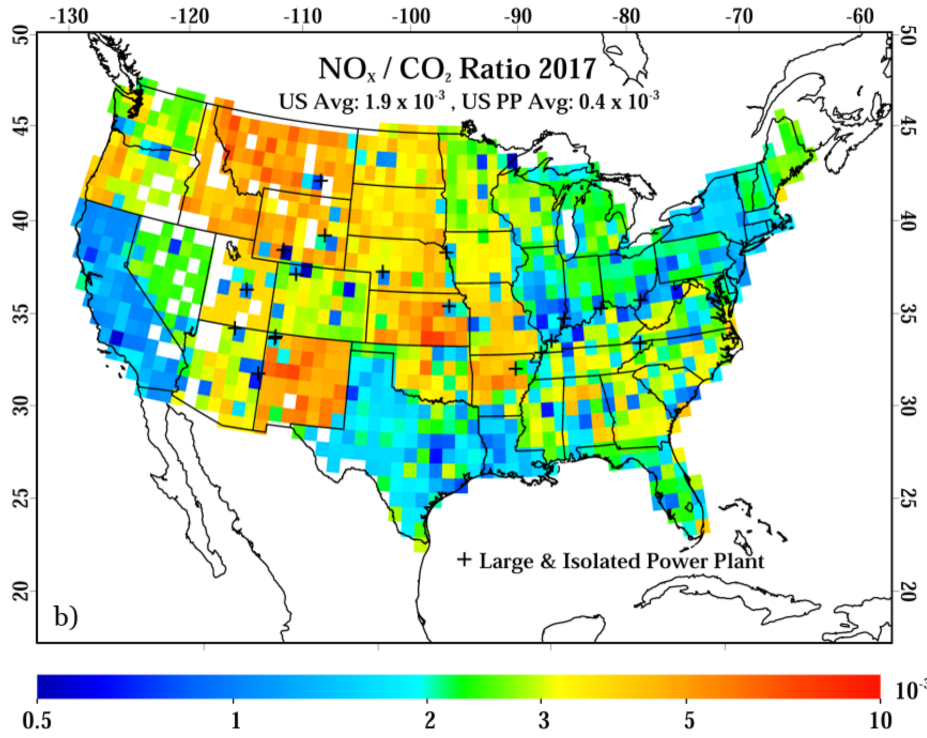
NO_X-TO-CO_2 RATIOS FROM THE INVENTORY

NO_x-to-CO_2 ratios computed to 100 × 100 km^2 grid boxes

2005

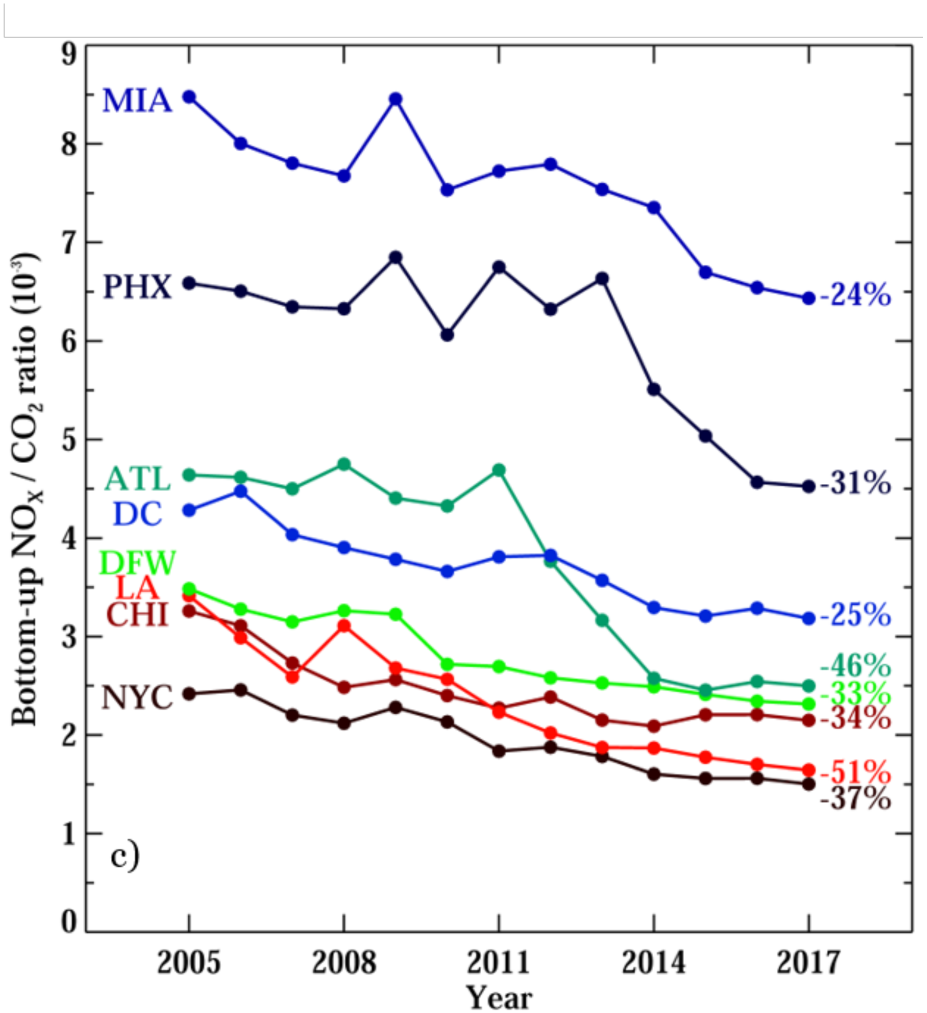


2017



- NO_x has been controlled more effectively than CO_2 (due to AQ regulations).
- Spatial heterogeneities across US → Larger ratios in central US, in compliance with $PM_{2.5}$ and O_3 standards, and no vehicle emissions monitoring.
- Discontinuities at state borders are an artifact of the state-by-state inventories.

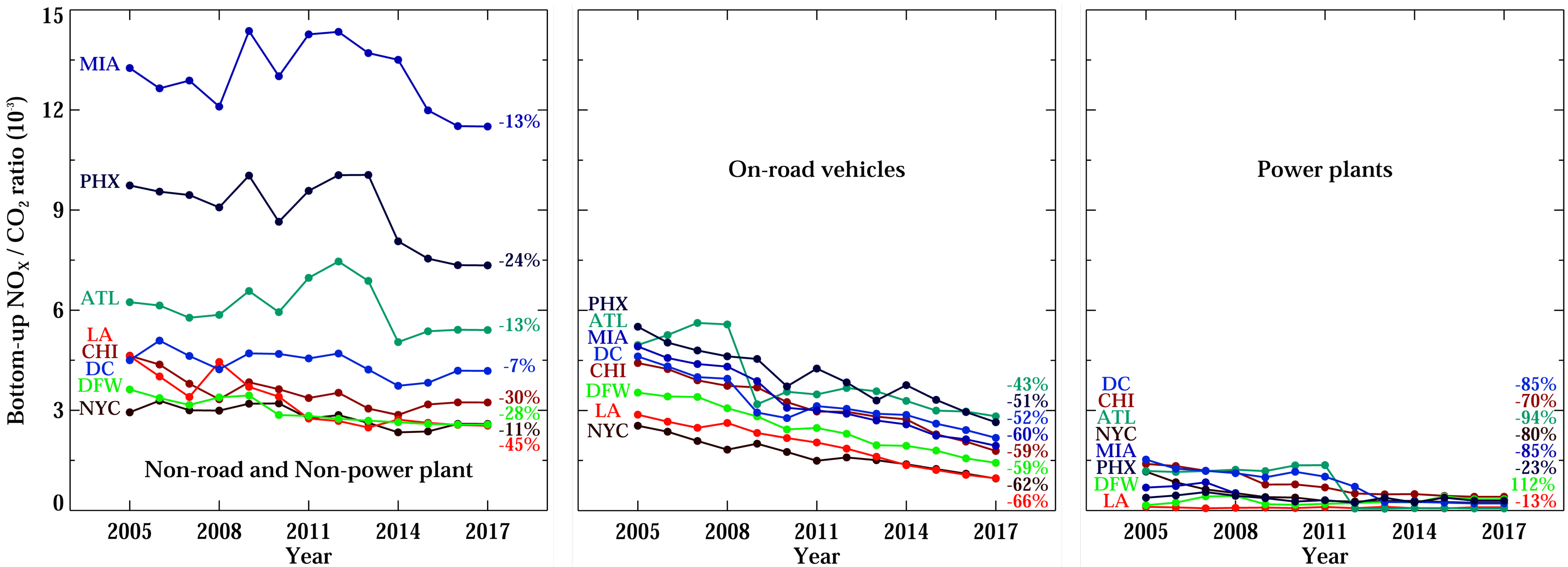
REGIONAL DIFFERENCES IN THE NO_X-TO-CO_2 RATIO



- Larger cities with a legacy of O_3 and $PM_{2.5}$ problems, have stricter regulations for NO_X for all sources.
- NO_X-to-CO_2 ratios can differ by a factor of 3 regionally!
- While the ratio has inherent uncertainties, the regional differences are likely valid due to varying regulations, economic activity, and lifestyles.

SECTOR BY SECTOR NO_X-TO-CO_2 RATIOS

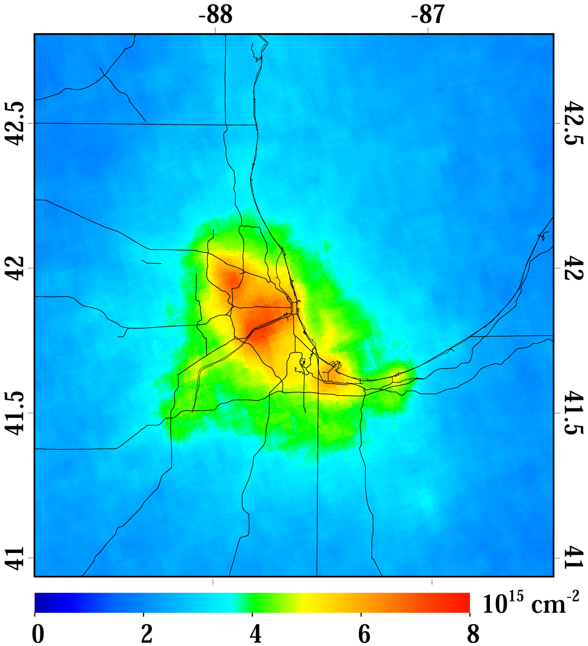
Emissions ratios vary greatly by sector!



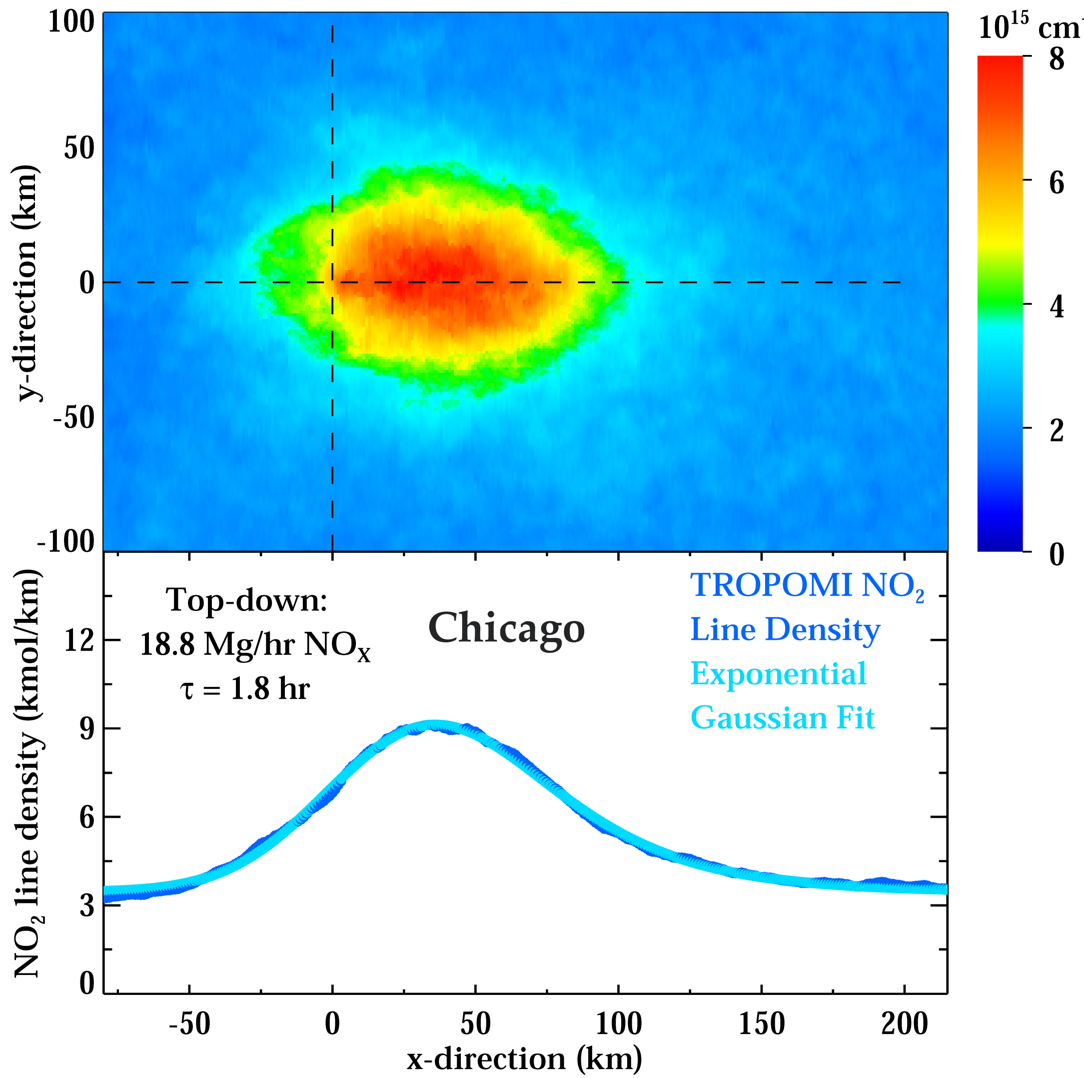
- Urban areas *roughly* have an equal distribution of NO_X from on-road vehicles, power plants, and non-road non-power plant sources.
- Certainty of emissions: Power plant > On-road > All other sources

HOW TO DERIVE EMISSIONS FROM SATELLITE DATA

Step 1: Isolate data from a single source (showing TROPOMI NO_2 for 2018)



Step 2: Rotate based on each day's winds



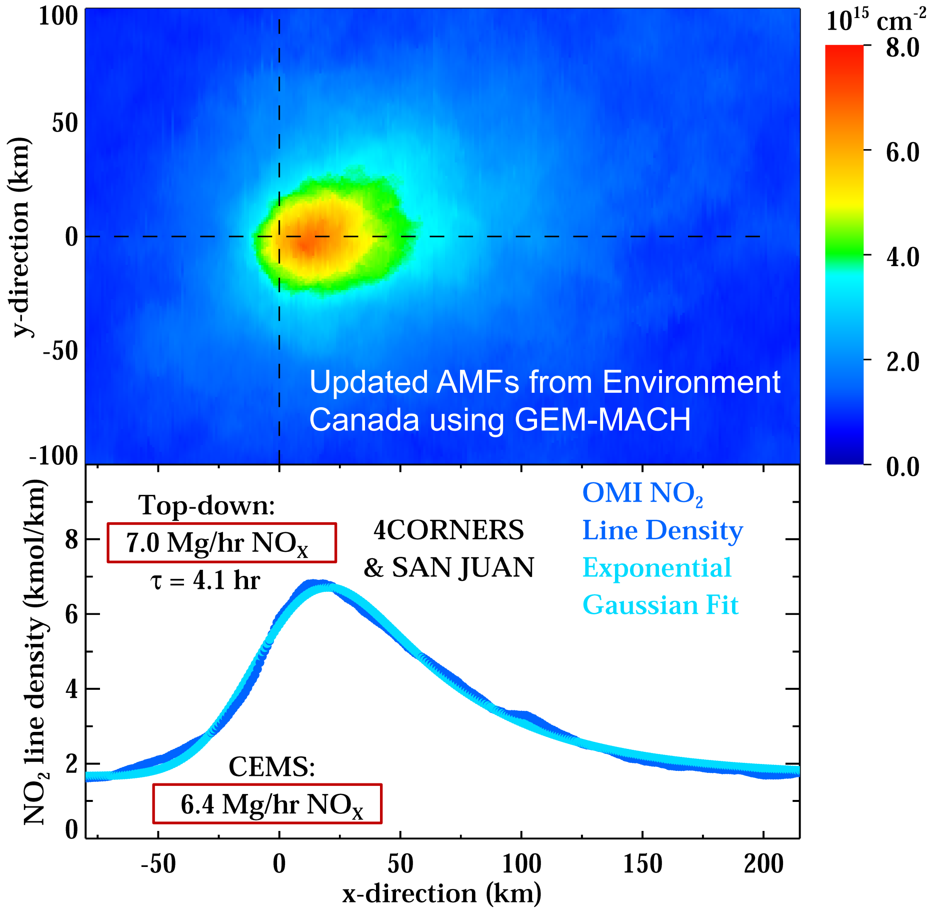
Step 3: Fit the decaying plume to an exponentially modified Gaussian function

Step 4: The fit will give a burden and decay distance, which can be used to calculate the emissions rate and lifetime

HOW DO WE KNOW THIS METHOD WORKS???

We compare to known NO_X emissions sources: US power plants

OMI NO_2 with updated AMFs

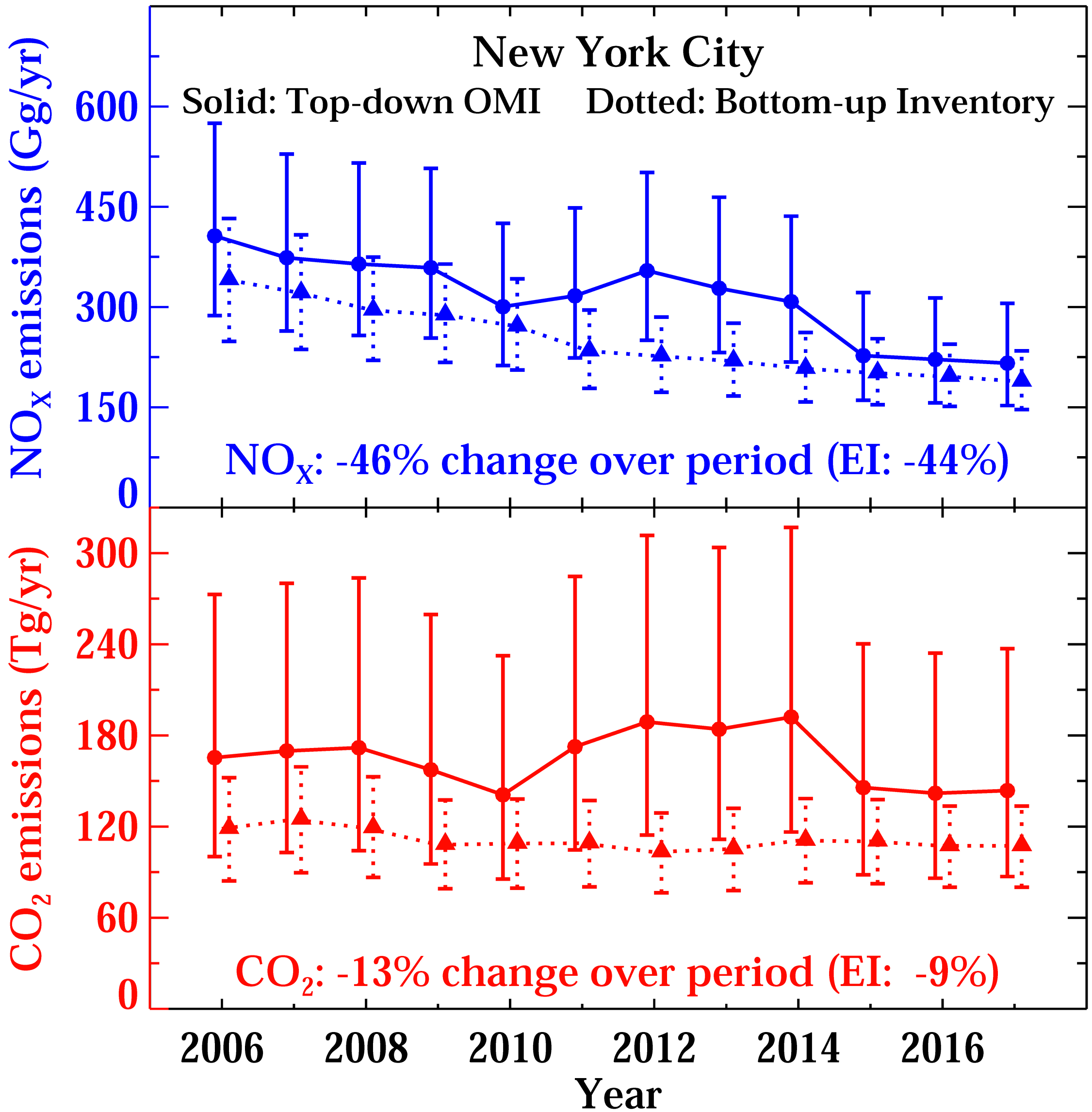


- After re-processing satellite data with regional air mass factors, there is generally agreement between the top-down method and the reported emissions (CEMS) to within ± 15%.

For more info on the satellite re-processing methodology see: McLinden et al., 2014; ACP, Goldberg et al., 2017; ACP

For more info on the inverse modeling method see: de Foy et al., 2014, 2015 AE; Goldberg et al., 2019; ACP.

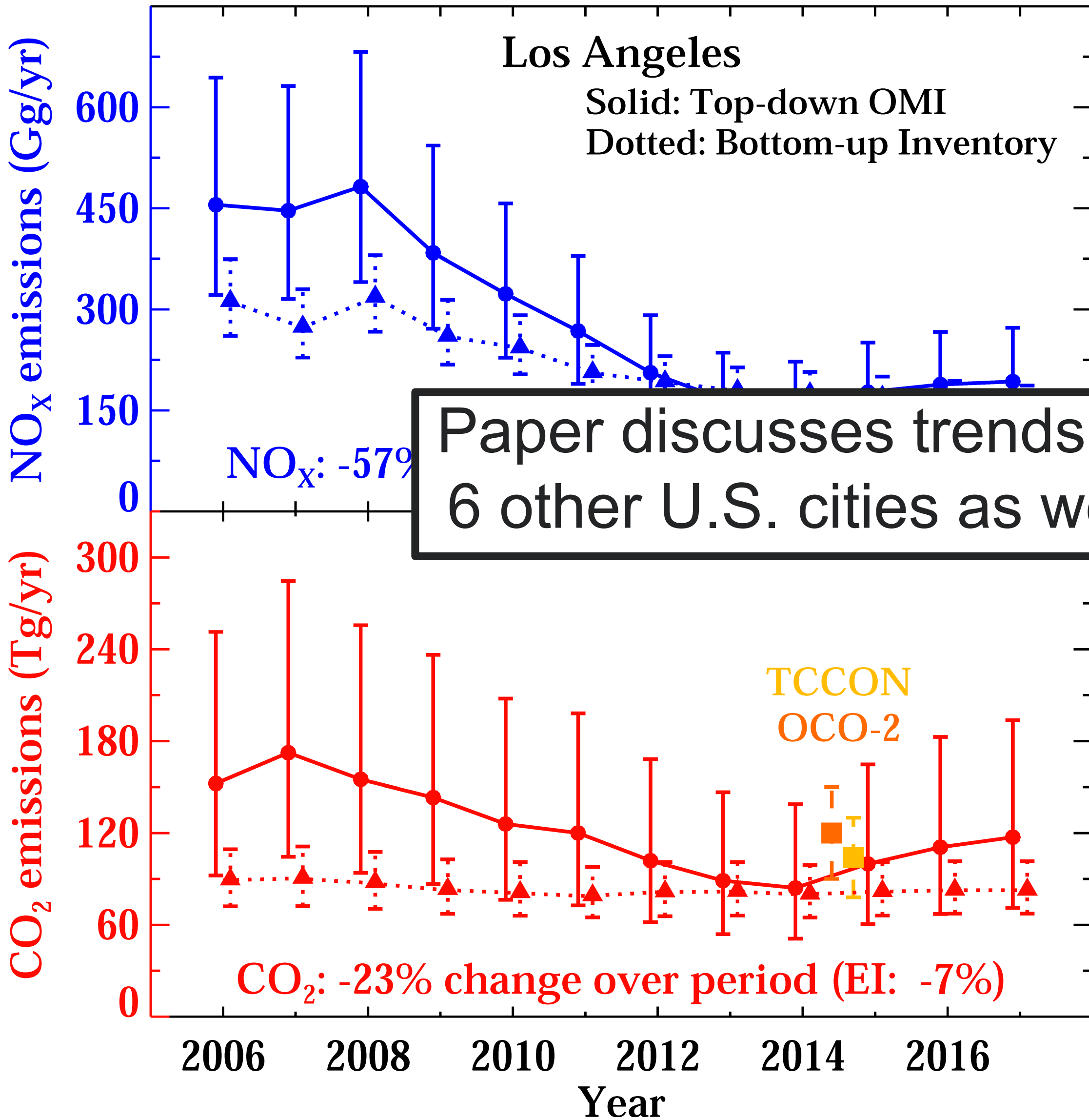
DERIVING "TOP-DOWN" OMI EMISSIONS: NO_X & CO_2 NEW YORK CITY



Top-down NO_X computed using oversampled OMI data over a 3-year warm season (e.g., 2006 = Apr thru Sept 2005 thru 2007)

Top-down CO_2 computed by dividing the top-down NO_X emissions rate by the local (within 75 km radius) NO_X-to-CO_2 ratio.

DERIVING "TOP-DOWN" OMI EMISSIONS: NO_X & CO_2 LOS ANGELES



Paper discusses trends for 6 other U.S. cities as well.

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CONCLUSIONS

- Investigated the NO_X-to-CO_2 ratios for various regions of the United States
  - Declines in the ratio over time due to NO_X controls
  - Spatial heterogeneity in the ratio

- Derived top-down NO_X emissions and trends for 8 U.S. megacities
  - In general, good agreement between our estimates and EPA inventories, but some interannual discrepancies.
  - Re-processing the air mass factor is an important step in the top-down method.

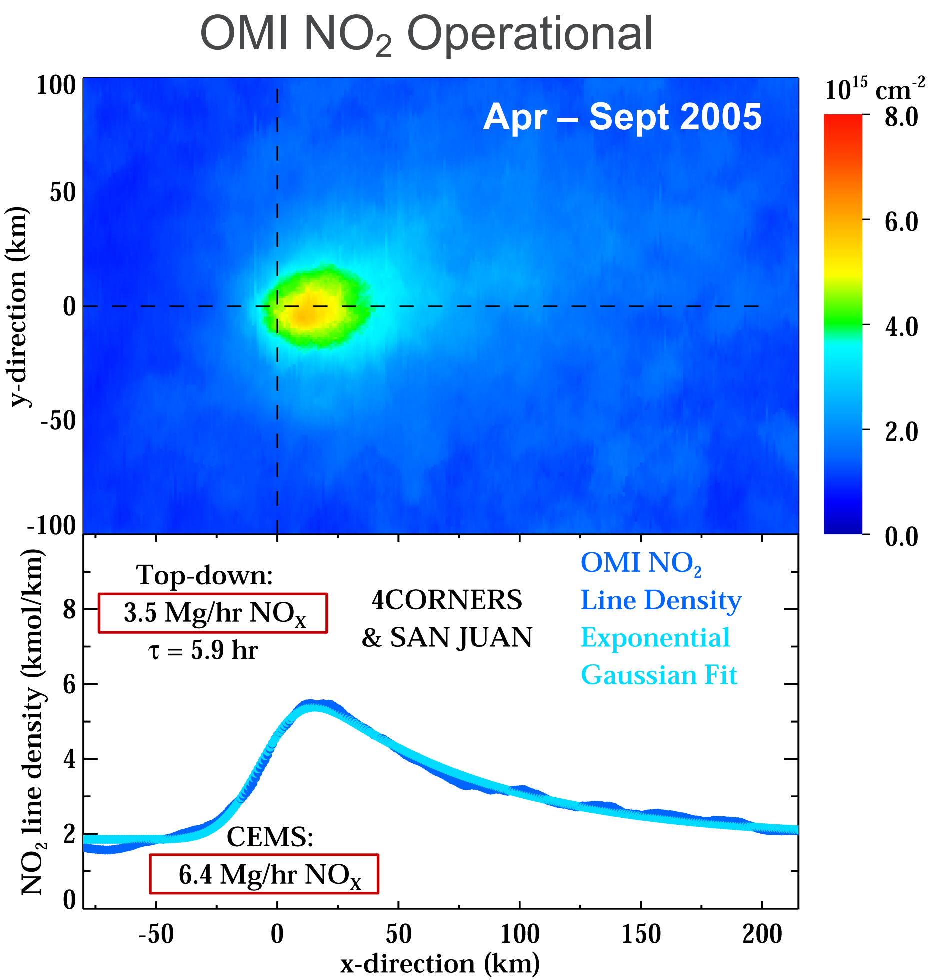
- “OMI” CO_2 emissions have been calculated
  - For the Los Angeles area, there is good agreement between our method and other top-down studies.

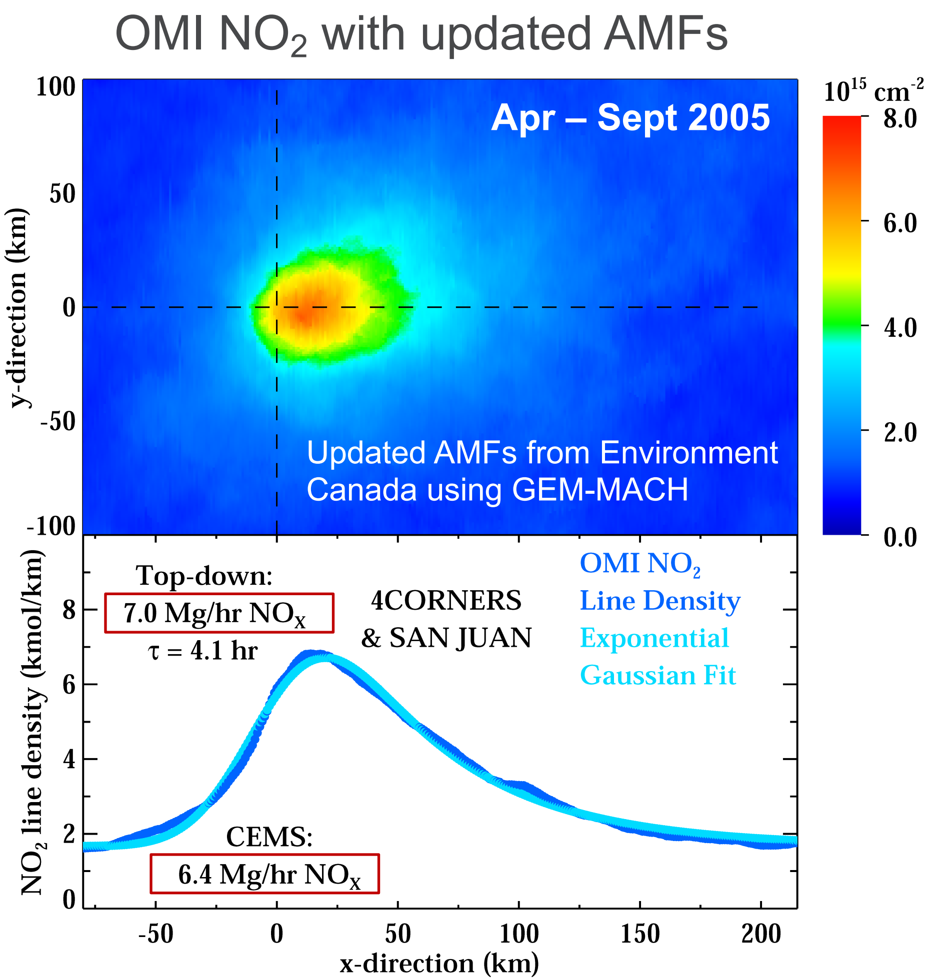
Email: dgoldberg@anl.gov or dgoldberg@gwu.edu

Thank you!

HOW DO WE KNOW THIS METHOD WORKS???

We compare to known NO_X emissions sources: US power plants





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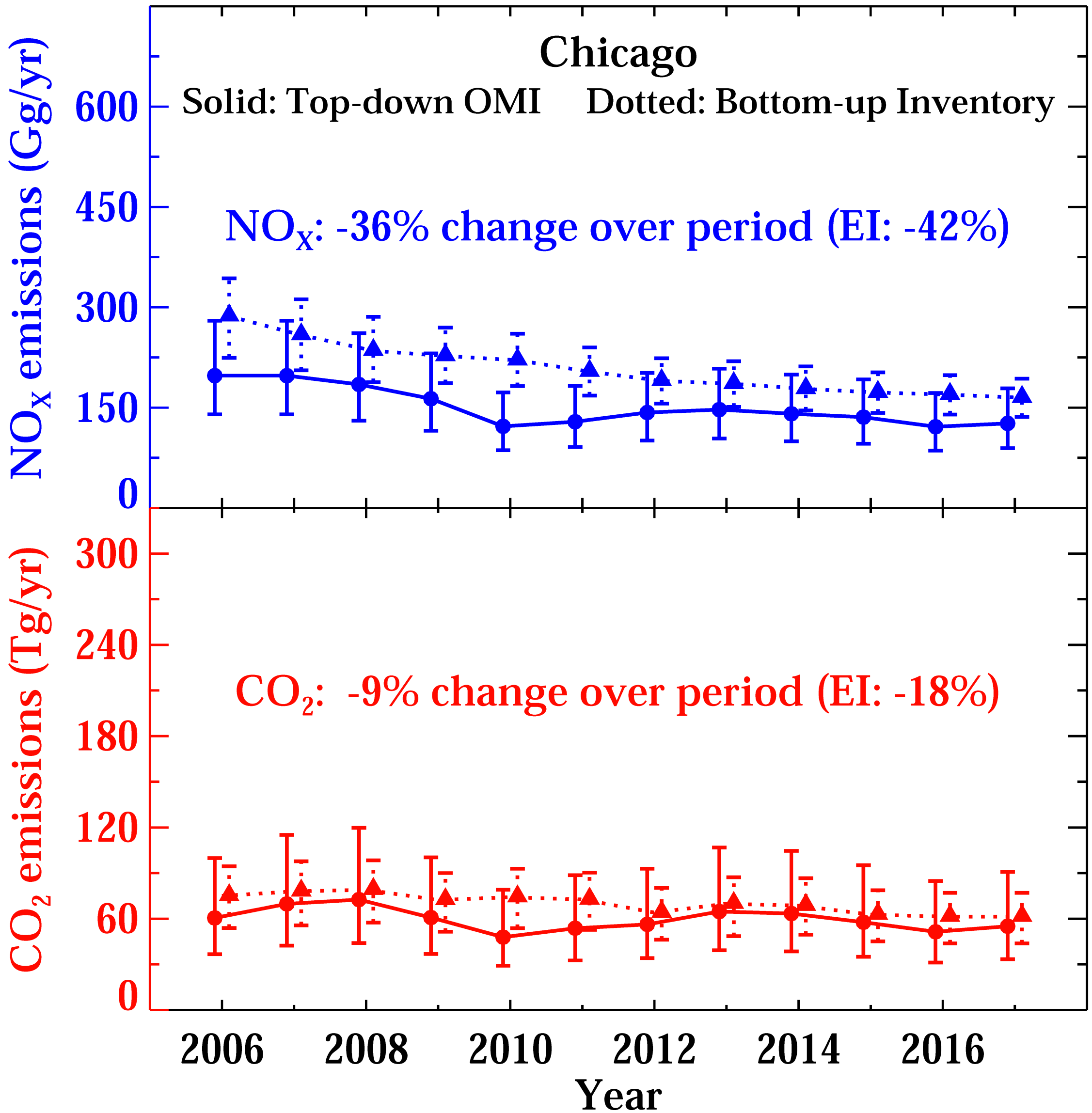
DERIVING "TOP-DOWN" OMI EMISSIONS: NO_X & CO_2 CHICAGO



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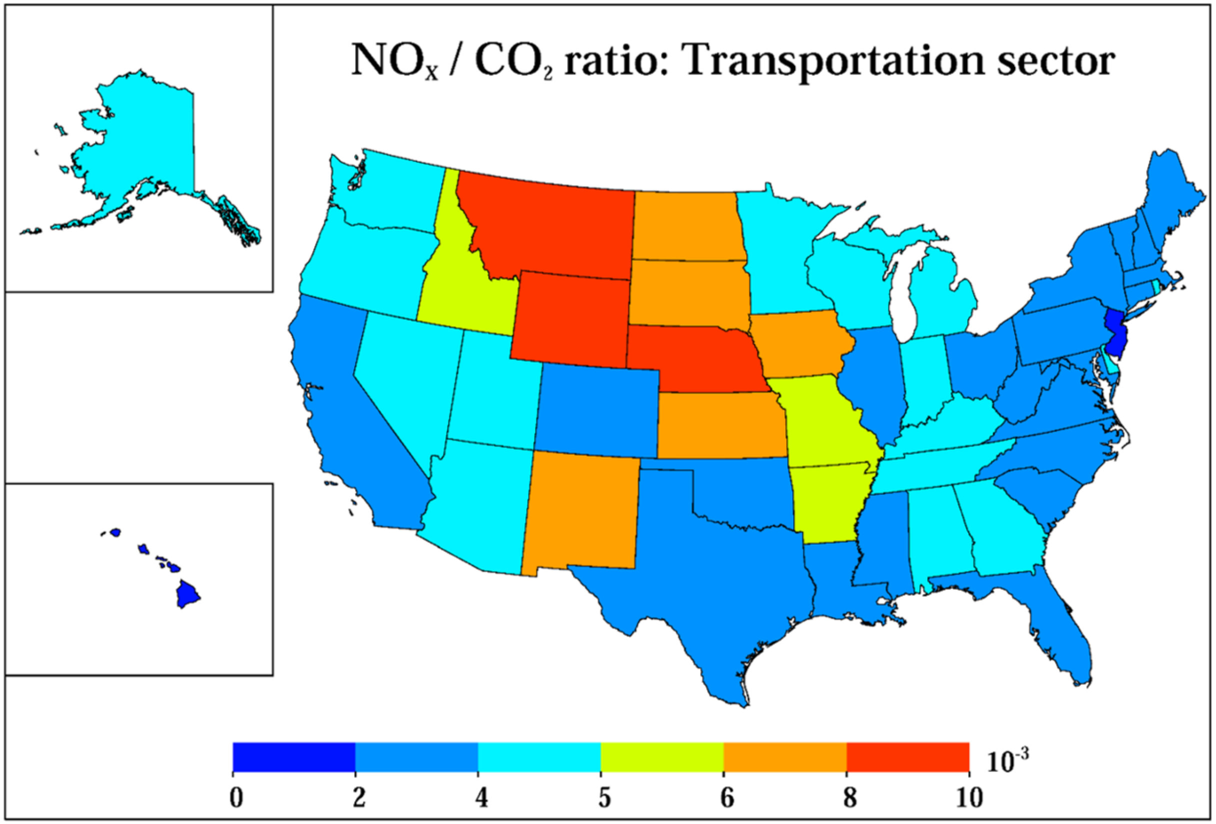
NOX AND CO2 EMISSIONS BY CITY

City	Inventory	NOx (Gg/yr)			CO2 (Tg/yr)		
		2006	2017	% change	2006	2017	% change
New York City	Top-down	407	216	-46.9%	165	144	-13.1%
	Bottom-up	340	188	-44.6%	119	107	-9.5%
Chicago	Top-down	197	126	-35.8%	60	55	-9.0%
	Bottom-up	287	165	-42.5%	75	61	-18.2%
Los Angeles	Top-down	445	193	-56.7%	147	113	-23.0%
	Bottom-up	261	134	-48.6%	72	67	-6.6%
Dallas	Top-down	64	48	-25.2%	20	21	6.5%
	Bottom-up	128	96	-24.9%	33	35	6.9%
Atlanta	Top-down	61	35	-42.9%	13	13	0.0%
	Bottom-up	77	47	-39.3%	14	15	6.3%
DC	Top-down	82	43	-47.3%	18	13	-26.3%
	Bottom-up	94	54	-42.7%	18	15	-19.2%
Miami	Top-down	56	46	-16.9%	7	7	4.0%
	Bottom-up	54	41	-24.5%	6	6	-5.5%
Phoenix	Top-down	78	39	-49.6%	14	10	-31.1%
	Bottom-up	53	37	-29.2%	8	8	-3.1%

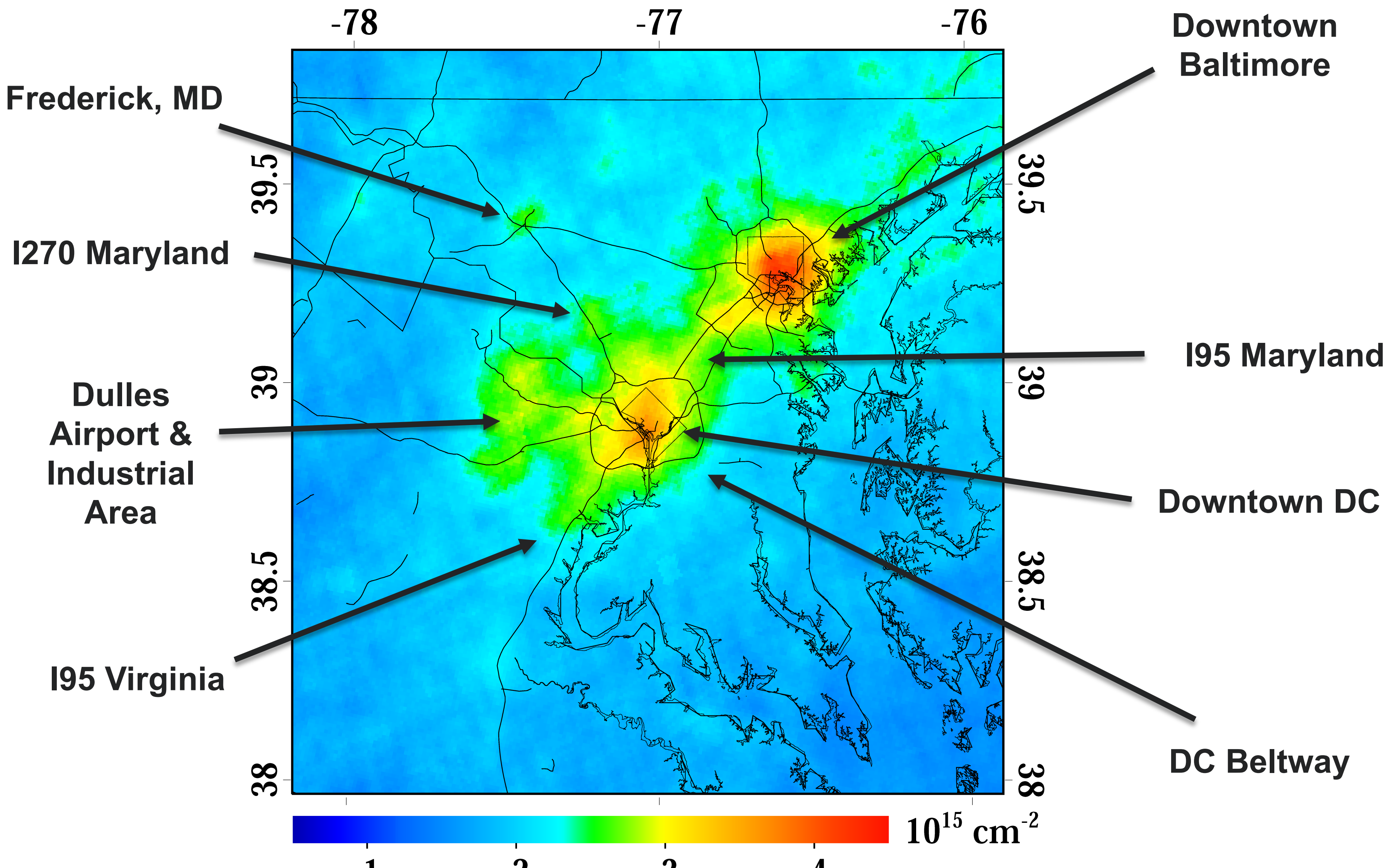
EXAMPLE OF STATE-REPORTED NO_X-TO-CO_2 RATIOS TRANSPORTATION SECTOR



- NO_X-to-CO_2 ratios are up to a factor of 3 larger in central Plains states when compared to east/west coast states. Causes are likely due to:
    - Older & less efficient catalytic converters in cars in these states → No state emissions checks!

OVERSAMPLED TROPOMI NO_2 FOR BALTIMORE & DC

May – September 2018



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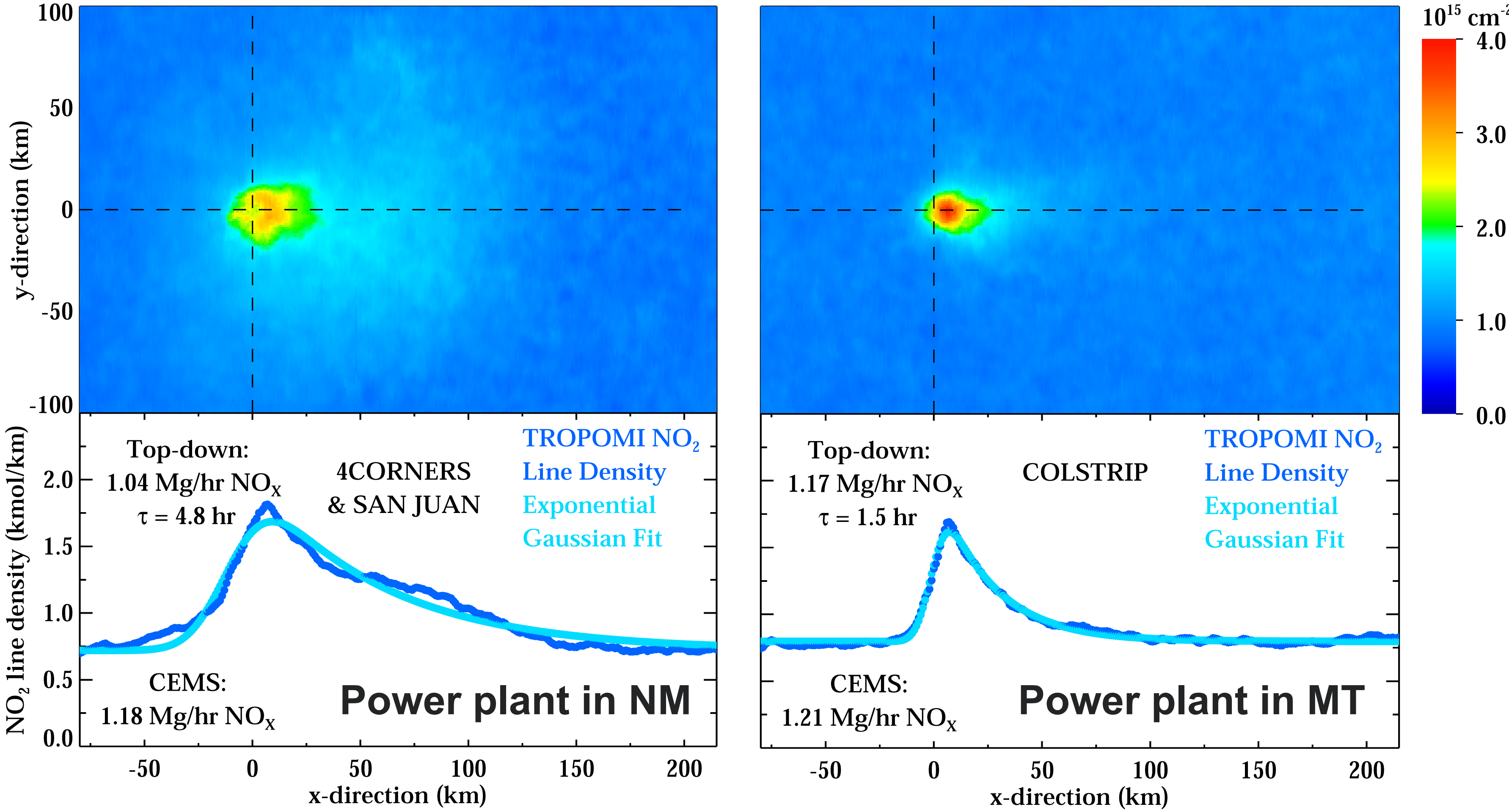

Excellent agreement. Within ± 15%. Also see de Foy et al., 2015.